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ON THE HEIGHT OF AURORAL ABSORPTION, II

BY

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ABSTRACT

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Statistical data from Alouette and Injun 3 giving the average precipitation rate of electrons in the auroral zone as a function of energy, are analyzed with regard to the average radio wave absorption produced by ionization by electrons in the energy ranges 1 - 40 kev and 40 - 250 kev. From the satellite data, it is found that the higher energy range for the primary electrons is the dominating one in producing absorption at riometer frequencies. From this it follows that the majority of auroral absorption takes place below 90 km altitude in the auroral zone.

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Introduction

The observation of a very small difference between ionospheric absorption of cosmic radio noise associated with aurora and magnetic distrubances, so called auroral absorption, before and after sunrise and sunset as compared to what was expected from existing models has made the height of auroral absorption a parameter of great importance for the understanding of the electron reactions in the lowest ionosphere (cf. e.g. Hultqvist 1963 a, b, 1964). There would be fewer difficulties in obtaining consistency between different types of experimental results if the auroral absorption could be shown to take place mainly in the height interval where the light emissions are mostly produced, i.e. in the E-layer. Proposals have been offered that, in fact, this is what in general occurs (Brown and Barcus, 1963). Several kinds of observational data indicate, however, that most of the auroral absorption is caused by ionization well below the E-layer (cf. Hultqvist, 1962, 1963 b, 1964).

Recently more observations relevant to the height of auroral absorption have been obtained. Ansari (1963) has analysed more carefully than before the correlation between auroral type of absorption and visual aurora and has found that "auroral absorption" is not one well defined type of phenomenon but contains at least two absorption phenomena different with regard to the energy characteristics of the ionizing corpuscular radiation. While some radio wave absorption is well correlated with the intensity of visual aurora, especially in the early part of the night, he found that there is one type, occurring after local midnight, that is not correlated with the light intensity. This is the type of auroral absorption which is causing the morning peak of the diurnal variation of the absorption in the auroral zone. The low light emission per absorption unit indicates that the energy of the primary electrons is much higher than for the electrons that cause the visible aurora. The increased penetrability of the higher energy electrons produces the enhancements in ionization much deeper in the atmosphere.

New extensive multiple-frequency riometer measurements of auroral absorption (Little et al., 1963, Lerfald et al., 1964) have shown that some 60% of 112 studied cases had the maximum in the absorption-per-km of altitude for 20 Mc/s cosmic radio noise at an altitude higher than 72 km, while for some 10% of the cases the maximum absorption-per-km was located at or below 60 km altitude. The multi-frequency absorption technique provides height information in the altitude range 35-75 km. It cannot tell whether there is some significant amount of absorption taking place up in the E-layer in the presence of absorption also in the 35-75 km interval, for instance. But even so the fact that in some 40% of 112 auroral absorption cases studied the peak absorption-per-km was at or below 72 km taken together with the fact that bremsstrahlung x-rays are probably negligible in producing riometer absorption (Ansari 1963, Hultqvist 1963 c, 1964, Brown, 1964) is enough for demonstrating the importance of higher energy electrons penetrating well below the visible aurora. The above-mentioned new results were obtained from ground observations of cosmic noise absorption.

Measurements on satellites (Mann et al., 1963) of the primary particles which cause the absorption have shown that there sometimes exists an influx of electrons with a spectrum so flat that the absorption-per-km height-profile caused by them has its maximum at about 70 km (Hultqvist, 1964). The total absorption produced by these observed flat-spectrum-electrons is higher than that caused by the steep electron spectra of McIlwain (1960) type, observed in visible aurora, even for very strong aurorae. These direct observations of the primary particles thus showed that at least sometimes most of the auroral absorption is located below 90 km altitude. However, due to the short life time of the satellites from which the measurements were made (only a few days) no good statistical information about the occurrence frequency of the various types of primary electron spectra was obtained. It is the purpose of this note to point out that the measurements by means of Alouette (McDiarmid et al., 1963) and Injun 3 (O'Brien, 1964) of precipitation of electrons into the atmosphere make it possible to attain a rough idea about how important the electrons in the energy ranges 1 - 40 kev and 40 - 250 kev, respectively, are for producing the auroral absorption, and, therefore, to provide another piece of experimental information independent of the ground observation of cosmic noise absorption about the height distribution of the auroral absorption. This information, in principle, covers the whole height interval of interest, contrary to the multi-frequency riometer measurements.

Satellite observations of electron precipitation in the auroral zone

McDiarmid et al. (1963) have reported results of electron flux measurements on board the Alouette satellite during several hundred passes through the auroral zone at an altitude of about 1025 km in the period October 1962 through January 1963. The measurements of special interest here were made by means of two Geiger-Müller tubes having electron energy thresholds of 40 and 250 kev. McDiarmid et al. found that the electron spectrum becomes progressively softer and very variable above about 59° invariant latitude. The flux of electrons with energy greater than 40 kev precipitated into the atmosphere had its maximum at an invariant latitude of 65 to 67°. The data were analyzed for two different ranges of K_p, namely < 4 and > 4. The average flux of precipitated electrons at the maximum in the auroral zone was found to be 3.10^5 electrons/cm^2sec ster for the high K_p range and 10 times less for the low K_p range. The half value width of the latitude distribution was some 8 degrees for $K_p > 4$ and about 12 degrees for $K_p < 4$.

On the average, the peak intensity of precipitated electrons with energies greater than 250 kev occurred at an invariant latitude of 60° and was approximately $1.9 \cdot 10^3$ electrons/cm^{2}sec ster and $2.6 \cdot 10^3$ electrons/cm^{2}sec ster for the low and high ranges of K_p, respectively. The latitude spread was found to be smaller than for 40 kev electrons.

Because no detailed latitude distribution of the flux of 250 kev electrons is given by McDiarmid et al., we will assume that the average fluxes at an invariant latitude of 65° is down by a factor of ten from the peak values mentioned above. This latitude correction is probably too large (i.e. the correction factor 0.1 is too small) as judged from a comparison of the latitude distribution of passes in which the intensity of precipitated electrons with energies greater than 250 kev was greater than $3.2 \cdot 10^3$/cm sec^{2}ster (Fig. 8 of McDiarmid et al., 1963) and the corresponding diagram for 40 kev. The resulting spectra are thus too steep rather than too flat. The absorption caused by electrons in the energy range 40 - 250 kev is therefore probably larger, rather than smaller, than the values presented below.

From the two integral flux values given above for each range of magnetic activity we can derive equivalent two-parameter spectra. For $K_p < 4$ an exponential equivalent differential spectrum is found to be $n\ (E) = 2.10^3 e^{-E/41}$ electrons/cm sec ster kev and for $K_p > 4$: $n\ (E) = 3.8.10^4 e^{-E/30}$ electrons/cm^{2}sec ster kev.

An equivalent two-parameter average differential spectrum for the primary electrons in the energy range 1 - 40 kev can be obtained from the results of the Injun 3 measurements presented by (O'Brien, 1964).

The data were taken in early 1963 at altitudes between 237 and 2785 km. The inclination of the orbit of Injun 3 was 70.4° and the satellite thus passed over the central polar cap over northern Canada. O'Brien gives the average integral flux for precipitated electrons with $E \geq 40$ kev as 4.10^5 electrons/cm^{2}sec in the auroral zone. This was obtained by means of a Geiger-Müller tube. A CdS-detector on Injun 1 gave the energy flux associated with electrons of energy greater than about one kev. The integral flux of 4.10^5 electrons/cm^{2}sec corresponded to an energy flux of about 4 ergs/cm^{2}sec. O'Brien and Taylor (1964) state that these data can be considered as accurate to a factor of about 3. Corresponding to these two average flux values is the average equivalent exponential spectrum $n(E) = 7.8.10^7 e^{-E/5.7}$ electrons/cm^{2}sec kev. This spectrum is fairly close to the spectrum ($\propto e^{-E/5}$) considered in some numerical detail by Hultqvist (1964). In fact $n(E) = 2.4 \cdot 10^8 e^{-E/5}$ electrons/cm^{2}sec kev gives the same integral electron flux for $E \geq 40$ kev as $7.8.10^7 e^{-E/5.7}$ electrons/cm^{2}sec kev, but the corresponding energy flux for $E \geq 1$ kev is 9 ergs/cm^{2}sec instead of 4. In fact the energy input rate per unit of light emission rate obtained with the value 9 ergs/cm^{2}sec is 5 ergs/cm^{2}sec per kR, which is midway between the corresponding values of McIlwain (1960) and O'Brien (1964) (cf. Hultqvist, 1964b).

Relations between average integral fluxes measured in satellites and average absorption values

The radio-wave absorption for the riometer frequency 27.6 Mc/s in the auroral zone is given for the ordinary ray by the Appleton-Hartree expression as

$$A = 0.46 \int_0^\infty \frac{N_e \nu}{3.34 \cdot 10^{16} + \nu^2} \, dh \qquad \text{db},$$

where N_e is the electron density and ν the electron collision frequency. The temporal structure of the electron precipitation measured by Alouette and Injun 3 is unknown. However, if the equilibrium relation between N_e and the ionization rate, q(h), is used for evaluation of electron density and absorption, overly large values will certainly be obtained. Since the effective recombination coefficient decreases from 60 to 100 km altitude the overestimation will be most important in the upper part of this height interval. The relative contribution to the absorption from the lowest part of the height interval mentioned will therefore be higher than what is found below in this note. It does not seem probable that the error in the average electron density in the lowermost part of the height range 60 to 100 km due to unequilibrium would exceed a factor of two, since the rate of variation of the electron density, as seen on riometer records, generally is slow compared with the recombination time in that part of the ionosphere. As such an inaccuracy does not invalidate the conslusions drawn in this note we thus write

$$N_e(h) = \left\{ q(h) / \alpha_{eff} \right\}^{1/2} \quad \text{and}$$

$$\bar{A} = 0.46 \int_0^\infty \frac{\nu}{3.34 \cdot 10^{16} + \nu^2} \overline{\left\{ \frac{q(h)}{\alpha_{eff}} \right\}^{1/2}} \, dh ,$$

where the bars indicate average values for the time function in question.

The data obtained from the above-mentioned satellite measurements above the atmosphere are the following time-average values:

$$\int_{40}^{\infty} \overline{n(E)} \, dE = \overline{N(>40)} \quad \text{electrons/cm}^2\text{sec},$$

$$\int_{250}^{\infty} \overline{n(E)} \, dE = \overline{N(>250)} \quad \text{electrons/cm}^2\text{sec},$$

and $$\int_1^\infty \overline{E\,n(E)}\,dE = \overline{\phi(>1)} \qquad \text{ergs/cm}^2\text{sec.}$$

Here $\overline{N(>40)} = \frac{1}{m}\sum_{i=1}^{m} N_i(>40)$, $\overline{n(E)} = \frac{1}{m}\sum_{i=1}^{m} n_i(E)$ and

$$\overline{E\,n(E)} = \frac{E}{m}\sum_{i=1}^{m} n_i(E) = E\,\overline{n(E)}.$$

$N_i(>40)$ represents a single satellite measurement of the integral flux above 40 kev energy. The average ionization rate at height h is given by

$$\overline{q(h)} = \frac{1}{Q}\frac{d}{dh}\int_0^\infty E\,\overline{n(E,h)}\,dE \qquad \text{electrons/cm}^3\text{sec,}$$

even if the electron precipitation is not homogeneous over a large area, due to the effect of the geomagnetic field. Q is the average amount of energy used in producing one electron-ion pair (35 ev in molecular nitrogen) and n(E,h) is the omnidirectional differential flux of electrons of energy E at altitude h. For a given particle energy, E, and angular distribution outside the atmosphere, n(E,h) can be written

$$n(E,h) = n(E) \cdot F(E,h)$$

where n(E) is the omnidirectional differential flux outside the atmosphere and F(E,h), which contains the information about the angular distribution outside the atmosphere, gives the attenuation in the atmosphere. Thus

$$\overline{q(h)} = \frac{1}{Q}\int_0^\infty \overline{E\,n(E)\,\frac{dF(E,h)}{dh}}\,dE = \frac{1}{Q}\int_0^\infty E\,\overline{n(E)}\,\frac{dF(E,h)}{dh}\,dE,$$

where the last equality is true if $\frac{dF}{dh}$ is the same for all fluxes used in the averaging i.e. if the directional distribution of the electrons outside the atmosphere does not vary from one passage to another. This is, of course, not necessarily so, but there is some experimental support for angular distribution being identical, namely isotropic, at least in the cases of intense precipitation (O'Brien, 1964), i.e. in those measuring values that contribute most to the average. It was also pointed out by Hultqvist (1964 a) that the radio wave absorption produced by an $e^{-E/5}$ differential spectrum of electrons entering the atmosphere vertically is smaller by less than 50% of its value than the absorption produced by an isotropic flux of identical energy distribution but of 2π times greater omnidirectional flux value. The variation of the directional distribution of the precipitated electrons from one precipitation event to another does therefore probably not affect the average significantly, and it is neglected in the considerations below.

When the two energy ranges about which information was obtained from Injun 3 (1 - 40 kev) and Alouette (40 - 250 kev) are considered, it can be found by numerical computations that the contribution to $\bar{q}$ from particles outside the energy ranges is negligible.

Thus we can write, with the use of the mean value theorem for integrals, for the low energy range

$$\overline{q_{1-40}(h)} = \frac{1}{Q}\int_1^\infty E\,\overline{n(E)}\,\frac{dF(E,h)}{dh}\,dE =$$

$$= \frac{1}{Q}\left\{\frac{dF(E,h)}{dh}\right\}_{E_1}\int_1^\infty E\,\overline{n(E)}\,dE = \frac{1}{Q}\left\{\frac{dF(E,h)}{dh}\right\}_{E_1}\overline{\Phi(>1)},$$

where E_1 is a value between 1 and ∞, and for the high energy range

$$\overline{q_{40-250}(h)} = \frac{1}{Q}\int_{40}^\infty E\,\overline{n(E)}\,\frac{dF(E,h)}{dh}\,dE =$$

$$= \frac{1}{Q}\left\{E\,\frac{dF(E,h)}{dh}\right\}_{E_2}\cdot\overline{N(>40)}.$$

If we, for instance, adopt the approximate formula for F(E,h) of Maeda (1963) and derive a two parameter average energy distribution from $\overline{N(>40)}$ and ϕ (> 1) for the energy interval 1-40 kev and from $\overline{N(>40)}$ and $\overline{N(>250)}$ for the interval 40-250 kev, simple closed expressions can be derived for $\left\{\frac{dF(E,h)}{dh}\right\}_{E1}$ and $\left\{E\,\frac{dF(E,h)}{dh}\right\}_{E2}$.

If the differential energy distribution corresponding to the experimental average integral flux values are assumed to be exponential in both energy intervals the expressions are as follows:

$$\left\{\frac{dF(E,h)}{dh}\right\}_{E_1} = -2\pi\rho(h)\,\frac{e^{1/b_1}}{b_1(1+b_1)}\int_1^{\infty} E\, e^{-E/b_1}\,\frac{1}{\sigma(E)}\,Ei\left(-\frac{x}{\sigma(E)}\right)dE \quad (4)$$

and

$$\left\{E\,\frac{dF(E,h)}{dh}\right\}_{E_2} = -2\pi\rho(h)\,\frac{e^{40/b_2}}{b_2}\int_{40}^{\infty} E\, e^{-E/b_2}\,\frac{1}{\sigma(E)}\,Ei\left(-\frac{x}{\sigma(E)}\right)dE. \quad (5)$$

b_1 is the e-folding value in the energy interval 1-40 kev and b_2 in the range 40-250 kev. $1/\sigma\,(E) = 3.18.10^6\,E^{-2.2}$ (Maeda, 1963) and Ei $(-x/\sigma)$ is the exponential integral defined by $-Ei(-y) = \int_y^{\infty} e^{-z}z^{-1}dz$. x is the atmospheric depth in g/cm^2, ρ(h) is the atmospheric density, and E is everywhere measured in kev.

We thus see that $\overline{q\,(h)}$ can be expressed in terms of the satellite-measured averages ϕ (> 1) and $\overline{N(>40)}$. But the average cosmic noise absorption is given in terms of $\overline{q^{\frac{1}{2}}}$ in (1) and not in terms of $\overline{q}$.

However,

$$\left(\overline{q^{1/2}}\right)^2 = \left\{\frac{1}{n}\sum_{i=1}^{n} q_i^{1/2}\right\}^2 = \frac{1}{n^2}\left\{\sum_{i=1}^{n} q_i + \sum_i q_i^{1/2}\sum_{j\neq i} q_j^{1/2}\right\} =$$

$$= \frac{1}{n^2}\left\{n\overline{q} + (n-1)n\,\overline{q^{1/2}}\cdot\overline{q^{1/2}}\right\} = \frac{1}{n}\overline{q} + \left(1-\frac{1}{n}\right)\left(\overline{q^{1/2}}\right)^2.$$

Thus $$\overline{q^{1/2}} = \left(\overline{q}\right)^{1/2} \quad \text{if} \quad \sum_{j\neq i} q_j^{1/2} = (n-1)\,\overline{q^{1/2}}.$$

Numerical calculations show that $\overline{q^{\frac{1}{2}}}$ and $(\overline{q})^{\frac{1}{2}}$ do not differ by as much as 50% even for a small number of terms and for ratios between the various q_i as high as 10^5.

We can therefore write with sufficient accuracy for the considerations below:

$$\overline{A_{1-40}} = \frac{0.46}{Q^{1/2}} \left\{ \overline{\phi(>1)} \right\}^{1/2} \int_0^\infty \frac{\nu\, \alpha_{eff}^{-1/2}}{3.34 \cdot 10^{16} + \nu^2} \left[\left\{ \frac{dF(E,h)}{dh} \right\}_{E_1} \right]^{1/2} dh \qquad (6)$$

$$\overline{A_{40-250}} = \frac{0.46}{Q^{1/2}} \left\{ N(>40) \right\}^{1/2} \int_0^\infty \frac{\nu\, \alpha_{eff}^{-1/2}}{3.34 \cdot 10^{16} + \nu^2} \left[\left\{ E \frac{dF(E,h)}{dh} \right\}_{E_2} \right]^{1/2} dh \qquad (7)$$

where

$$\left\{ \frac{dF}{dh} \right\}_{E_1} \quad \text{and} \quad \left\{ E \frac{dF}{dh} \right\}_{E_2}$$

may be obtained from (4) and (5), respectively. The average absorption is thus expressed in terms of the average integral fluxes measured by the satellites.

The integrands in (6) and (7) depend only on atmospheric properties and the average flux as function of energy and can therefore be evaluated from satellite-measured average spectra. If the average spectrum is defined only in two points, as is the case with the Injun 3 and Alouette results, an assumption has to be made about the shape of the spectrum between those points. Exponential spectra are used below. The main uncertainty in the results obtained is certainly due to the limited amount of available statistical data and the enormous variation that there is in it, while the uncertainty in the detailed shape of the spectrum between the measuring points probably introduces only minor uncertainties.

Electron density profiles and absorption due to the equivalent average spectra

The exponential electron energy spectrum for $K_p < 4$ is exactly the same as the spectrum for which Hultqvist (1964) calculated the height profile. The equilibrium electron density curve No. 1 in Fig. 1 has been obtained from Hultqvist's (1964) results by multiplying by $\sqrt{2/70}$. Hultqvist's computations were made for vertically incident electrons of energy spectrum proportional to exp(-E/41). However, the absorption produced by $ce^{-E/41}$ electrons/cm^{2}sec kev, entering the atmosphere vertically, is probably less than that caused by $ce^{-E/41}$ electrons/cm^{2}sec ster kev, having isotropic directional distribution outside the atmosphere, by less than 50% of this higher value. The total absorption for a frequency of 27.6 Mc/s expected from the electron density curve No. 1 in Fig. 1 is 0.32 db.

An upper limit to the electron density profile and total absorption produced by an electron energy spectrum of $3.8.10^4 e^{-E/30}$ is obtained from $3.8.10^4 e^{-E/41}$, which in turn can easily be found from the values computed by Hultqvist (1964). In this way curve No. 2 in Fig. 1 has been derived. The corresponding limiting total absorption for radio waves of frequency 27.6 Mc/s is 1.4 db. Probably the correct value for the spectrum with an e-fold value of 30 kev is close to 1 db. A lower limit for it is, of course, the value given above for $K_p < 4$ (0.32 db).

For the equivalent average spectrum for the range 1 - 40 kev, $2.4.10^8 e^{-E/5}$ electrons/cm^{2}sec kev, the numerical calculations of Hultqvist (1964) can be employed. The electron density profile No. 3 in Fig. 1 has been derived by means of them. The total absorption at 27.6 Mc/s due to this electron density profile is 0.09 db.

Discussion

The increase of the pitch angle of an electron due to the magnetic forces when it passes along the field line down into the atmosphere has not been taken into account. As all measurements were made close to the earth's surface this neglection does certainly not introduce any large error. Its effect, if any, would be to increase the height of the ionization produced by the particle precipitation.

There are several simplifying assumptions and approximations made, which tend to make the deduced effect of the electrons in the energy range 40-250 kev too small relative to that of the 1-40 kev electrons. One is that Hultqvist's (1964a) numerical values for vertically penetrating electrons have been employed. As mentioned earlier, this may make the absorption too small by not more than 50% of the value for the case of isotropic electron angular distribution outside the atmosphere, and by still less of the value for the electrons in the loss cone. A second fact contributing to the computed absorption value for 40-250 kev electrons being too small is that the equivalent average spectrum in this energy interval is probably less steep than the spectra used in the numerical estimations. A third approximation working in the same direction is that the equilibrium relation between electron density and the ionization rate was used. This makes the computed absorption overestimated. Since the effective recombination coefficient decreases from 60 km upwards the overestimation will be most important at greater heights. It does not seem probable that the error in the average absorption per unit height in the lowermost part due to unequilibrium would exceed a factor of two, since the rate of variation of the electron content, as seen on riometer records, mostly is slow compared with the recombination time in that part of the ionosphere.

On the other hand there was an assumption made which tends to make the contribution by electrons in the 1-40 kev range too small compared to that of the 40-250 kev electrons. The average precipitated electron flux above 40 kev energy was given by O'Brien as 4.10^5 electrons/cm^2sec. It was assumed above that this omnidirectional flux was isotropic over the upper hemisphere just outside that level where the energy loss of the electrons starts to be significant, i.e. at 200 km, say. This is probably not far from the truth, but the flux may have been limited to a somewhat smaller solid angle than 2 π. Had this real angular distribution been known and taken into account the calculated absorption would have been somewhat greater.

Although only the order of magnitude of the absolute values of absorption seems to be significant, the ratio of contributions of the two energy intervals of precipitated electrons, discussed in this note, is probably uncertain by no more than a factor of three. A more accurate analysis than the one given above seems not worthwhile or possible on the basis of existing experimental data.

The electron density profiles in Fig. 1 as well as the total absorption values derived from them are those for the daytime. On the night side of the earth the electron densities may possibly be somewhat lower than those in Fig. 1 for altitudes less than 90 km due to negative ion production.

The values used as basis for the model spectra are average fluxes. The range of variation is, as mentioned, very large. O'Brien (1964) found that there was always some precipitation in the auroral zone. The lowest value observed by him there was about $2 \cdot 10^{-4}$ of his average value quoted above. The maximum values shown in his paper were about 15 times greater than the average. To these minimum and maximum values of the ionization rate correspond extreme values of equilibrium electron densities 70 times smaller and 4 times greater than the average respectively. McDiarmid et al. (1963) showed similar variation ranges.

The use of exponential model spectra was motivated simply by the fact that numerical values were already available from Hultqvist (1964). It should be remembered that each of these spectra were obtained from only two pieces of experimental information and they are only very rough descriptions of spectra which are not known in detail. If an equivalent spectrum is to be used, as in this case, there seems to be at least as good reasons to use exponential ones as power law spectra. The observational indications of a fairly flat spectrum without any "infrared catastrophy" below a few kev (O'Brien, 1964, O'Brien and Taylor, 1964) support the use of exponential spectra in the low energy range.

The observations of both McDiarmid et al. (1963) and of O'Brien (1964) indicate a fairly strong latitude dependence of the spectral slope and the equivalent spectra used above should therefore be considered as representative only in the auroral zone.

The average total absorption values for 27.6 Mc/s given above for the various electron spectra:

(a) $n(E) = 3.8 . 10^7 e^{-E/5}$ electrons/cm^{2}sec ster kev $A = 0.090$ db

(b) $n(E) = 3.8 . 10^4 e^{-E/30}$ electrons/cm^{2}sec ster kev $(K_p > 4)$ $A < 1.4$ db

(c) $n(E) = 1.9 . 10^3 e^{-E/41}$ electrons/cm^{2}sec ster kev $(K_p < 4)$ $A = 0.32$ db, indicate that the flat type of electron spectrum with e-fold values generally between 25-45 kev are the dominating one in producing auroral absorption in the average. The absorption due to these spectra takes place mainly between 60 and 90 km and not in the height interval where most visible aurorae are located.

The range of variation of the 27.6 Mc/s absorption corresponding to the wide variations of electron fluxes reported by McDiarmid et al. (1963) and O'Brien (1964) is from the order of 0.01 db to 4 db, if smoothing due to time constants in the ionosphere is neglected, and is caused by the variation of the flux of the hard spectrum electrons. It should be remembered that there were no strong geomagnetic storms included in the material presented by McDiarmid et al. (1963).

The absorption values computed from the satellite measured electron fluxes for the two ranges of magnetic activity are in quite good accordance with the multifrequency riometer measurements mentioned in the introduction, as well as with the average absorption during the five most disturbed days and five most quiet days in each month, as observed over several years at College (geomagnetic latitude 64.5°) by Basler (1963). For the disturbed days he found a daily average of about 1 db in the summer and between 1 and 2 db in winter and at equinoxes. For the quiet days the daily average obtained from his figure 7 is about 0.3 db.

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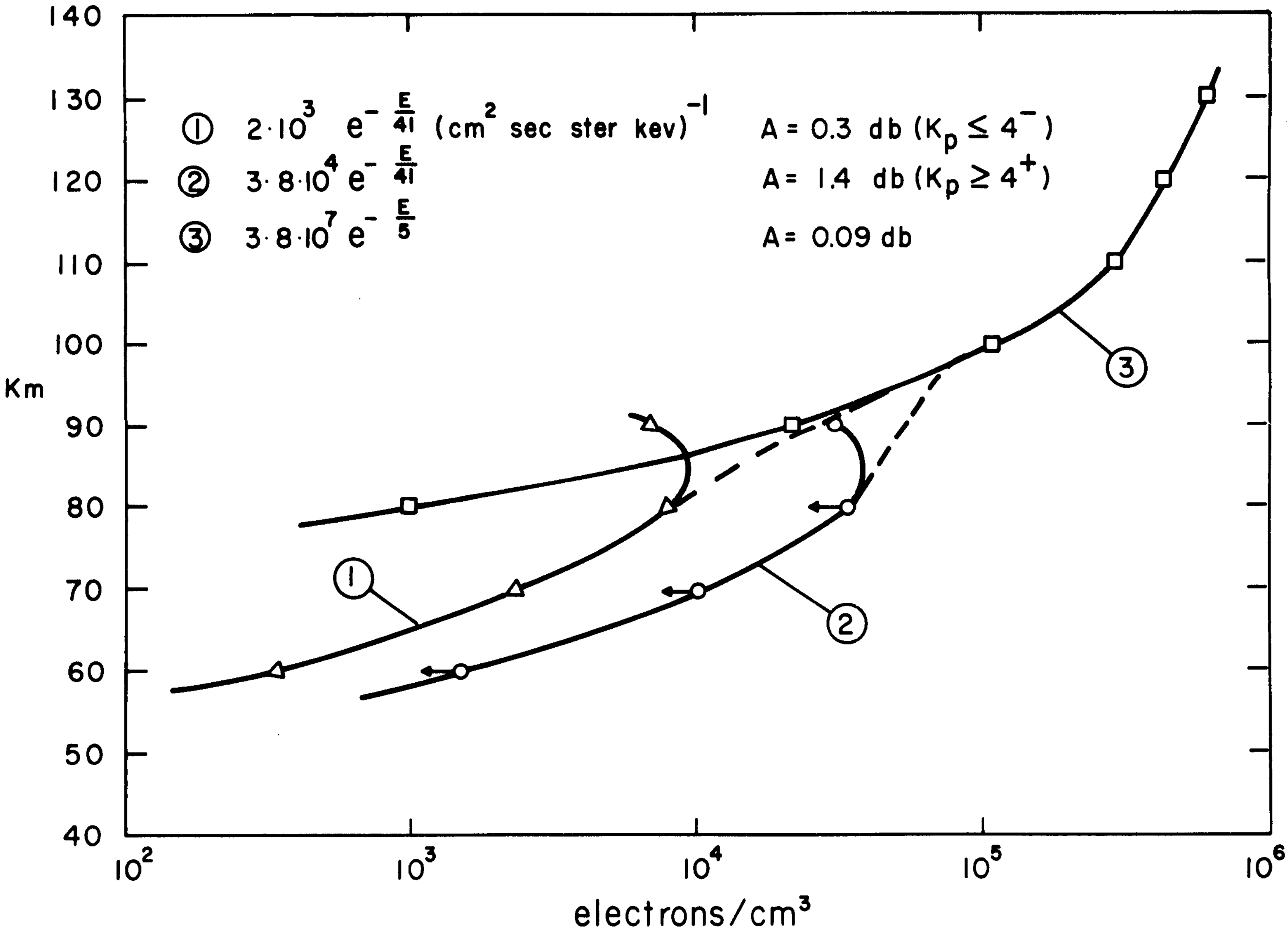
Figure Caption

Figure 1. Equilibrium electron density profiles due to three energy spectra of precipitated electrons. The spectra as well as the total absorption, A, at 27.6 Mc/s are given in the figure. Curve No. 2 gives an upper limit for the equilibrium electron density distribution produced by the spectrum $3.8 . 10^4 e^{-E/30} (cm^2 sec\ ster\ kev)^{-1}$. A lower limit for this spectrum is curve No. 1.



140
130
120
110
100
90
80
70
60
50
40
Km
① $2 \cdot 10^3 \, e^{-\frac{E}{41}}$ (cm^2 sec ster kev)$^{-1}$
② $3 \cdot 8 \cdot 10^4 \, e^{-\frac{E}{41}}$
③ $3 \cdot 8 \cdot 10^7 \, e^{-\frac{E}{5}}$
A = 0.3 db ($K_p \leq 4^-$)
A = 1.4 db ($K_p \geq 4^+$)
A = 0.09 db
1
2
3
10^2
10^3
10^4
10^5
10^6
electrons/cm^3